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THE PROBLEM OF ACTIVE LONGITUDES ON THE SUN /64

Yu. I. Vitinskiy

ABSTRACT

The position of the active solar longitudes is studied by the method of isolines. Choice of an unsuitable scale for measuring active areas in longitudinal direction, or of an incorrect zero reference point may lead to erroneous results when this method is used. The Deslandres 30^{o} longitudinal scale unit was chosen, because it covers the population belt of recurrent sunspots. Maps of isolines of sunspot areas have been drawn on which the active regions were isolated from others. That zero point was chosen which yielded the greatest mean longitudinal gradient in the maximum area of sunspots. The zero points of the Northern and Southern Hemispheres did not coincide in many cases. An irregular oscillation of the positions of active solar longitudes was noted on the maps which had been drawn and an attempt was made to find more accurate positions of the centers of active longitudes. The centers were shifted in one direction in the Northern Hemisphere but no such definite direction was noted in the Southern Hemisphere. Vitinskiy concludes that the subphotospheric layers associated with active longitudes rotate faster in some 11-year cycles and slower in others.

In a previous work (Ref. 1) we used the method of isolines to isolate the sun's active longitudes. By this method it was possible to reach some interesting conclusions about these longitude intervals. Of particular significance is the fact that the property of active longitudes was retained, to an accuracy equal to that of the scale used (40^{o} in units of heliographic longitude), for two or more of the 11-year solar cycles.

However, in using the isoline method, two problems deserve special consideration. Either of these problems, if solved incorrectly, can decrease the accuracy of isolating the active longitudes, because they produce an effect equivalent to intersecting the active regions. Such an effect can be caused either by improper choice of the area scale, (in particular of its longitude units, or by improper choice of the zero point.

First let us consider the question of the scale of areas along the longitude, because in studying the longitude distribution of sunspots, the choice of latitude scale is not so important for us. We note only that by stopping at $\Delta\varphi = 20^{\circ}$ we have, for practical purposes, chosen to consider the entire sunspot region with respect to latitude.

Deslandres (Ref. 2) studied the question of the breadth of the active solar longitudes in detail, and concluded, on the basis of consideration of a large amount of material on sunspots and photospheric faculas, that optimally sharp isolation of the active longitudes is attained using a 30° i.e., $\pi/6$ longitudinal scale unit. Subsequently, this result was reexamined by Salet (Ref. 3) who, on the basis of data on the photospheric faculas, determined that the most reliable scale unit was not $\pi/6$ but $\pi/5$, i.e., nearly 40°. Curiously enough, the latter conclusion practically coincides with that reached by Djurkovic (Ref. 4) with respect to the optimal dimensions of a group of sunspots.

However, because all the investigators cited above dealt with limited amounts of data, the problem of the optimal active longitude scale can scarcely be considered solved. Still earlier (Ref. 1) we noted that if a 20° longitude scale unit is selected, we get an extremely complicated and inaccurate picture of the longitude distribution of sunspot activity. On the other hand, a scale of 40° allows us to distinguish the active longitudes accurately. Since the basic populations of the active longitudes are recurrent groups of spots, it is pointless to treat scale variations of less than 10°. In this connection, it remained for us to study the possibility of using the method of isolines to construct a map of the sunspot regions with a 30° longitude scale.

An isoline map of the areas of sunspot activity with a $30^{\circ} \cdot 20^{\circ}$ area scale was constructed for the 16th sunspot cycle, for which we had earlier obtained (Ref. 1) a particularly sharp picture of the longitude distribution of sunspot activity, with an area scale of $40^{\circ} \cdot 20^{\circ}$. This gave a sufficiently accurate isolation of the active longitudes. However, it is very difficult to make an objective estimate of how much the variation of the scale improved or impaired the result. And furthermore, it appeared to us that the substantial variations which might have been observed did not occur. Therefore, if we are sufficiently objective, we may conclude only that a longitude scale of less than 30° is not suitable for the construction of an isoline map. But since the 30° and 40° scales do not give substantial differences, it is possible to choose a 40° scale, which was used before, possibly in order to compare the new results with the data obtained in Ref. 1. /65

In previous construction of an isoline chart of sunspot areas, we dealt with a fixed zero point longitude, equal to 360°. However, it is quite clear that we cannot be certain that in doing this, we are not going to intersect the active regions. Thus, it is advisable to vary the zero point, shifting it in one direction or the other, by amounts no greater than 10°, within the limits of the 40° scale we have chosen. We note that even varying the zero point for a fixed scale does not fully assure that we will not intersect the active region. Just the same, however, it can give some mean optimal conditions for the isolation of active longitudes, and this circumstance must be kept in mind in development of criteria for the best choice of the zero point.

We will consider that the zero point is best when the mean longitude gradient of ΣS_i in the given (Northern or Southern) Hemisphere of the sun is largest. Table 1 shows the values of these gradients for the Northern and Southern Hemispheres of the sun during the 12th through 18th cycles of solar activity for shifts of the zero longitude point to the east by 0°, 10°, 20°, and 30°, in arbitrary units.

The gradients of ΣS_i with respect to longitude are computed according to the formula

$$\left(\frac{\overline{\partial \Delta S_j}}{\partial \lambda}\right) = \frac{1}{2n} \sum_n \frac{\Sigma S_i - \Sigma S_k}{|i - k|},$$

Table 1

Cycle Number	Northern Hemisphere				Southern Hemisphere			
	0°	10°	20°	30°	0°	10°	20°	30°
12	2.3	2.0	<u>2.8</u>	2.3	<u>4.2</u>	2.0	2.5	2.5
13	2.7	2.4	2.5	3.3	2.1	2.9	2.7	<u>3.3</u>
14	3.8	<u>3.9</u>	2.4	1.8	3.0	4.1	<u>4.7</u>	3.2
15	<u>5.5</u>	3.8	4.4	4.3	2.1	3.9	<u>4.2</u>	2.9
16	3.2	<u>5.7</u>	3.7	3.0	<u>3.2</u>	2.8	1.9	1.8
17	5.1	4.7	4.3	<u>5.4</u>	3.8	3.4	3.2	<u>6.1</u>
18	<u>8.4</u>	4.6	6.7	5.9	<u>6.2</u>	6.0	6.1	2.4

where ΣS_i is the maximal value of the area, and ΣS_k is its minimal value, $|i-k|$ is the modulus of the difference of the indices of the areas, and n is the number of active longitudes. The coefficient 2 appears in the denominator because the averaging over each active longitude is carried out with respect to both sides of the maximal value ΣS_i. In this table the maximal values of the gradients are underlined.

As may be seen, in only two cases for the Northern Hemisphere, and in only three cases out of seven for the Southern, the choice of zero point made in Ref. 1 had a definite basis. On the other hand, it may be seen that the positions of the zero point in the Northern and Southern Hemispheres in many cases are not coincident. This deviation was greatest in the 12th and 15th cycles of solar activity. However, there is almost no regularity in the variation of this particular property. /66

After choosing the best zero point, we constructed the map of isolines of ΣS_i for the 12th through 18th cycles in a manner similar to that of Ref. 1.

As noted earlier in this article, the question of the stability of the active longitudes is most important for us. If we make a group map of the active longitudes during the 12th through 18th cycles, according to their geometric centers (see Fig. 1), then it is noticeable that they show a tendency to deviate to either side of some effective center and that these deviations are of an irregular character and basically not greater than $\pm 40^{\circ}$. Therefore, we still cannot say whether in the given case the active longitudes really oscillate or whether it is that they simply maintain practically the same longitude interval over a long period of time. This is particularly true for the Northern solar Hemisphere, in which three active longitudes existed during seven of the 11-year cycles of solar activity. In the solar Southern Hemisphere, the active longitudes were less stable, but there, too, their lifetime exceeded two solar cycles.

Our material, incorporating data on the areas in each 10° longitude interval, makes it possible for us to determine the centers of the active longitudes with substantially greater accuracy. It should be simple to separate the 10° intervals within the active longitudes in which ΣS_i is maximal. However, when such longitude intervals are also situated on the edge of the active longitude, and do not substantially exceed the value of ΣS_i in the remaining three longitude intervals, incorrect results are possible. Therefore, it seemed most resonable to us /67 to define the center of the active longitude as weighted over the area in 10° longitude intervals that make up the active longitude. To do this, we used the formula

$$\lambda_i = \lambda_{i0} + \frac{5(\Sigma S)_1 + 15(\Sigma S)_2 + 25(\Sigma S)_3 + 35(\Sigma S)_4}{(\Sigma S)_1 + (\Sigma S)_2 + (\Sigma S)_3 + (\Sigma S)_4}.$$

Here λ_{i0} is the Carrington longitude of the initial active longitude interval (from the zero point side), $\Sigma(S)_1$, ..., $\Sigma(S)_4$ are the values of ΣS_i in the 40° longitudinal intervals, proceeding from west to east. /68

By this method, we can determine the centers of the active longitudes to 10° accuracy. These centers for the 12th through 18th cycles of solar activity are given in Table 2.

Here, in the Southern Hemisphere, the average refers only to those active longitude intervals which are continuously maintained during the course of not less than two 11-year cycles. Fig. 2 shows shifts of centers of active longitudes from cycle to cycle. For increased accuracy, each shift is represented by a separate arrow. The figures near the beginning and end of each arrow designate the number of the 11-year cycle. The broken lines show the mean value of the center of active longitude for the entire period of its existence. As may be seen from Fig. 2, in most cases, we are dealing with actual shifts of centers of active longitude, since the shifts noticeably exceed 10°, i.e., the accuracy of determination of their centers. Such shifts have an irregular character, but in some degree suggest oscillatory motion. It is interesting that in the Northern Hemisphere of the sun, in the 12-14th and 16-18th solar cycles, in all three active longitudes the shift is directed to one side. In the Southern Hemisphere, the situation is somewhat more complex; but here too, we note that in the two most stable active longitudes (see λ_1 and λ_2 Table 2) the shifts in the 13-14th (λ_1) and 16-18th (λ_2) cycles are directed oppositely to the shifts in the Northern Hemisphere.

Thus, based on Table 2 and Fig. 2, we conclude that the centers of the active longitudes oscillate irregularly around some average value. We note that for the chosen latitude scale, we can say nothing, essentially, about the shifts of these centers with respect to the meridian.

It is of interest to determine the mean characteristics of the shifts of the centers of the active longitudes and to ask whether there is a connection between these and the average intensity of sunspot forming activity in these longitudes or the mean value of the variation of /69

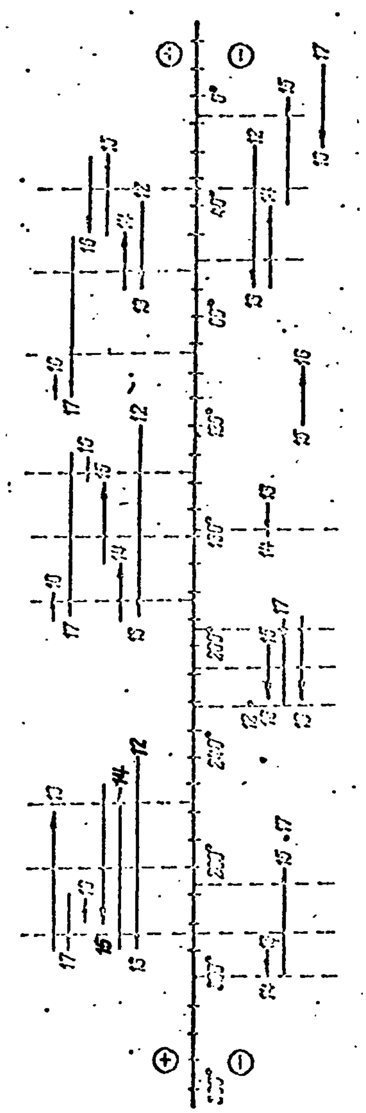

Figure 1.

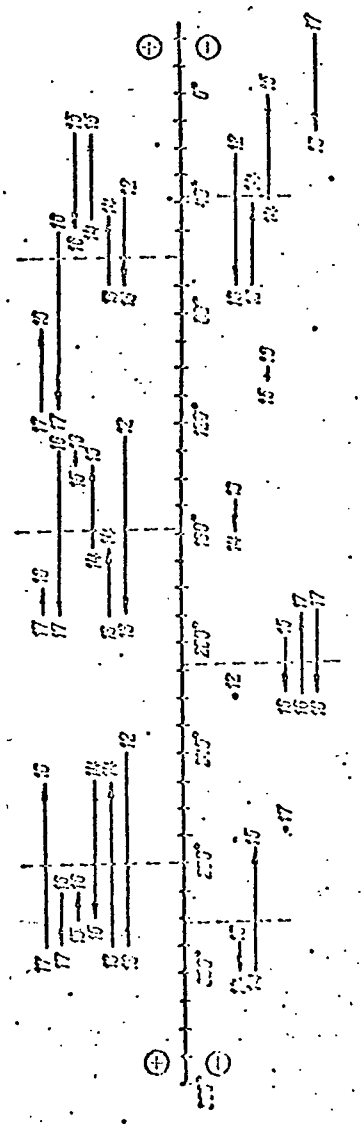

Figure 2.

intensity. Naturally, such calculation is reasonable only for such longitudes as are maintained for not less than three 11-year cycles. Hence, the longitudes λ_3 and λ_4 of the Southern solar Hemisphere (see Table 2) are not considered. Table 3 gives average moduli of the shifts of the centers of the active longitudes with respect to the parallels in degrees for the 11-year cycle, and also in cm/sec; the average value of ΣS_1; and the average moduli of the variation of ΣS_i from cycle to cycle

Table 2

Cycle number	Northern Hemisphere λ_1	λ_2	λ_3	Southern Hemisphere λ_1	λ_2	λ_3	λ_4	λ_5
12	240°	125°	40°		220°			25°
13	310	190	70	310°		150°		70
14	250	165	45	320		160		40
15	300	135	15	275	200		105°	0
16	290	130	50		220		100	
17	310	190	115	270	190			350
18	260	180	85		220			15
Average	280°	159°	60°	302°	208°	155°	102°	34°

Table 3

Longitude	Northern Hemisphere $\overline{\Delta V}_\lambda$ deg/cycle	$\overline{\Delta V}_\lambda$ cm/sec	$\overline{\Sigma S}_i$	$\overline{\Delta\Sigma S}_i$	Longitude	Southern Hemisphere $\overline{\Delta V}_\lambda$ deg/cycle	$\overline{\Delta V}_\lambda$ cm/sec	$\overline{\Sigma S}_i$	$\overline{\Delta\Sigma S}_i$
λ_1	43	150	11	2.7	λ_1	28	96	11	5.5
λ_2	32	113	12	3.0	λ_2	27	92	13	4.3
λ_3	36	124	11	2.8	λ_5	38	133	11	2.3

for these longitudes. For the enumeration of the active longitudes, the same designations as in Table 2 are used.

As may be seen from this Table, the intensities of the active longitude intervals being considered were practically identical and were not related to the magnitude of the average shift of their centers. At the same time, the values $\overline{\Delta V}_\lambda$ and $\overline{\Sigma S}_i$ shown in Table 3 are definitely interrelated. It is true that the relation yields no reliable quantitative estimate, mainly because of the small volume of material, but a qualitative deduction may easily be made from Figure 3. From this Figure it follows that the smaller the average value of the intensity variation of the active longitude, the greater the shift that it undergoes along the parallel from one 11-year cycle to another. The

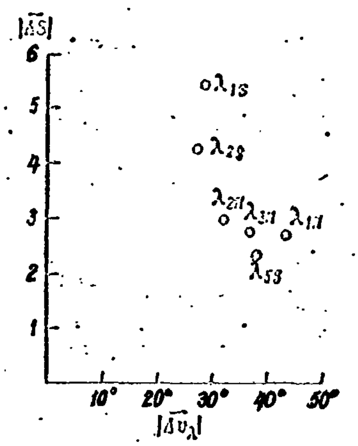

Figure 3

most reliable points are those λ_{1n}, λ_{2n} and λ_{3n}, obtained by averaging over seven solar cycles. It is possible that such a dependence of $\overline{\Delta V}_{\lambda}$ on $\overline{\Delta \Sigma S}_{i}$ for the active longitudes is explained by the fact that the active longitudes which are described by the sharpest variations of intensity in sunspot activity are closely connected with the deeper layers of the sun and therefore can not shift any significant distance from their original position. /70

Finally, we note that the shifts of the active longitudes along the parallel show that the subphotospheric layers to which they belong are rotated faster in some 11-year cycles and slower in others than the solar photosphere. These properties of the active longitudes require a theoretical analysis which is beyond the scope of this article.

In conclusion we take this opportunity to express our acknowledgement of helpful discussions with B. M. Rubashev and R. N. Ikhanov.

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